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ANALYSIS OF FLOW THROUGH POROUS MEDIA AS APPLIED TO GABION DAMS REGARDING THE STORAGE AND RELEASE OF STORM WATER RUNOFF

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Chapter 1

INTRODUCTION

The scope of this research effort is focused on flow through large-size porous media. This media is actually angular limestone rock, typically used in gabion dam structures. A gabion is basically a "basket of rocks." Typical applications of gabions include use in the construction of dikes and dams, underwater scour prevention around bridge piers, and as erosion stabilizers along river banks and coastlines. Within the past few years, innovative engineers have experimented with gabion dams as they relate to storm water management. The idea is to use these structures to detain and release storm water runoff. The concept is to design the gabion dam in such a way that the flow through the structure will meet the specified target release rates, typically predevelopment runoff rates.

The major concern with the use of gabions as outlet control structures is that their design is based upon practical experience and sound engineering judgement. The hydraulic flow-through properties of gabions have never been evaluated in a laboratory setting. This research effort attempts to (1) evaluate the flow through large-size porous media, (2) develop a gabion design equation(s), (3) route a design storm through a detention basin and gabion structure to validate the equation, and (4) formulate recommendations and conclusions.

Chapter 2

PRELIMINARY INFORMATION

2.1 Background Information

The term "gabion" can be traced back to the times of the Roman Empire. Derived from the Latin word for cage, a gabion is actually a hollow basket frame, constructed of metal strapping or wire mesh and filled with earth or stone. Originally gabions were used as barricades or ramparts designed to protect soldiers or as defensive fortifications.

Gabions have evolved to become an integral part of the water resources and hydraulic engineering fields. Figure 2.1 illustrates various gabion configurations. Gabion mattresses are used for scour prevention, for coastline protection, and for lining channels, as shown in Figures 2.2 through 2.4.

Recently gabions have been used in the control of storm water runoff. Their intended purpose was to retain the runoff and then release it at pre-specified rates. Gabion dams have several advantages over traditional dikes and outlet structures used in storm water management that make them a viable alternative approach: their base width is much smaller, they are virtually maintenance free, and some would say that they are aesthetically more pleasing.

Figures 2.5 and 2.6 show some gabion structures designed by Mr. Charles Weir, P.E., of Weir Associates, Inc., to control storm water flows. Mr. Weir used sound engineering principles, practices, and judgement in the design of these dams. The structures shown in these figures are located in Ambler, Pennsylvania, just north of Philadelphia, have been in place for over 15 years and seem to be functioning as intended. Figure 2.5 depicts the use of gabions in the control of residential storm water runoff. The structure is approximately 24 feet long, 3 feet wide, and a maximum of 3 feet in height. Figure 2.6 is a much larger dam measuring approximately 250 feet long, 9 feet wide at the base, and a maximum of 11 feet in height. This structure is particularly well adapted for this wooded site. Only three large-size trees had to be removed during its construction. A traditional earthen dam with 4:1 side slopes and a 10 foot width at crest elevation would have a base width of about 100 feet. This would necessitate the removal of dozens of trees, not to mention the cost of construction and fill material requirements.

One of the major drawbacks to the use of gabions is that the hydraulic flow-through characteristics of their large-size porous media have apparently never been tested in the laboratory. Further investigation was necessary. The authors visited Maccaferri Gabions Inc. in Williamsport, Maryland, the nation's largest producer and supplier of gabions. It was discovered that a great deal of research has been done on gabion structures; however, it has focused only on their hydraulic properties as related to soil stabilization in channels and on slopes. No documented research work has been performed on their flow-through characteristics. At this point it became evident that some laboratory flow tests and analyses were needed. The authors decided to conduct some preliminary flow tests on porous media. The Hydraulics Laboratory of the Department of Civil and Environmental Engineering at The Pennsylvania State University was selected as the test site.

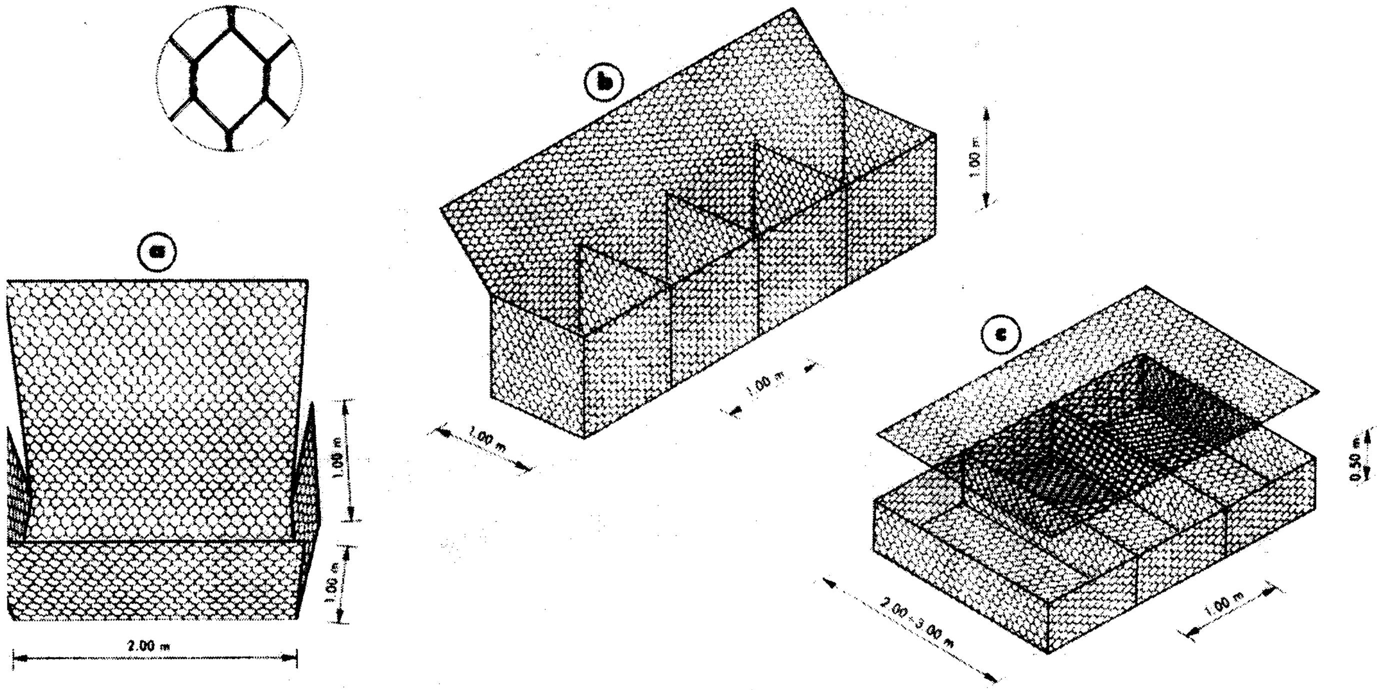

Figure 2.1. Examples of a Gabion: (a) without a diaphragm, (b) with a diaphragm, (c) with multiple cells. Courtesy of Maccaferri Gabion Inc.

Figure 2.2. Gabions Used to Protect Bridge Piers from Scour.
Courtesy of Maccaferri Gabion Inc.

Figure 2.3. Gabion Protected Coastline.
Courtesy of Maccaferric Gabion Inc.

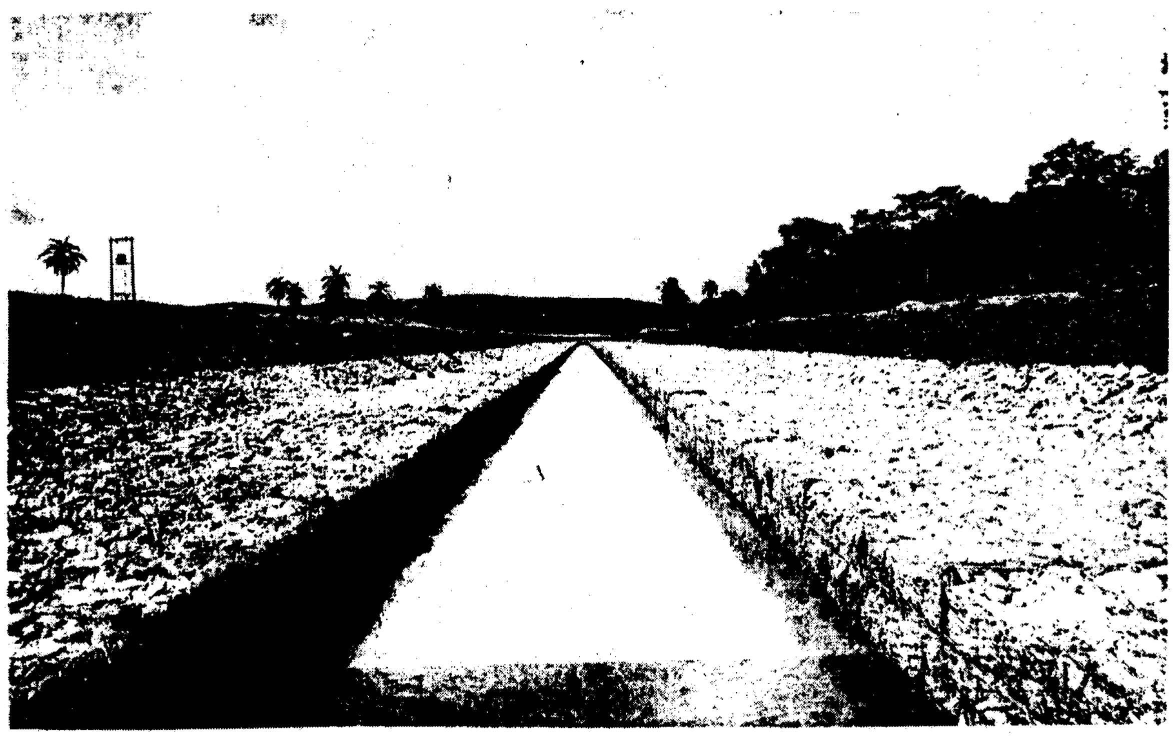

Figure 2.4. Gabion Lined Channel.
Courtesy of Maccaferric Gabion Inc.

Figure 2.5. Gabions Used in a Residential Development.

Figure 2.6. Large-Size Gabion Dam in a Wooded Area.

2.2 Laboratory Set Up: Phase I

The existing hydraulic flumes in the lab proved inadequate for the gabion research effort. The flumes were constructed of plexiglass, which would become severely scratched when in contact with the rock media, and were also too narrow. A minimum flume width of two feet was required to effectively negate the effects of side wall flow which could bypass the media. Therefore, a flume had to be constructed. Plywood was the material of choice since it was readily available at a minimum cost. An 8 foot long flume with a cross section of 24" x 22" was constructed from the plywood sheets. All joints were sealed with silicone compound. Figure 2.7 illustrates the partially constructed gabion flume.

One-half inch wire mesh was selected for the gabion basket framework. The basket width represents the flow path length. Widths of one foot and two feet were selected for these preliminary tests. The baskets were positioned in the flume approximately four feet from the PVC inflow piping to reduce turbulent effects. The flume was then raised into position above a weighing tank so that the outflow from the flume discharged directly into the tank and an accurate measure of the flow could be obtained. Two large piezometers were installed on the flume, one upstream and one downstream of the baskets, to read the upstream and downstream head. Nine smaller piezometer tubes were installed at the basket structure to provide a profile of the water surface. Water was then run through the flume to check for leaks and so that the weighing tank could be calibrated and checked for accuracy. Figure 2.8 shows the fully constructed flume, while Figure 2.9 is a close-up of the piezometer nest.

The angular limestone rock was obtained from a local quarry. Three different rock sizes were collected: 3-5" stone, 1-2" stone, and 3/4" stone. Approximately four cubic feet of each size was collected and transported to the laboratory. Samples of the three rock sizes are shown in Figure 2.10. Additionally, thousands of golf balls were borrowed from the Penn State Golf Course for use in this study, since some data concerning spherical media might prove useful.

With all the apparatus and material in place and in proper working order in the laboratory, flow tests could begin.

Figure 2.7. Partially Constructed Gabion Flume.

Figure 2.8. Finished Gabion Flume.

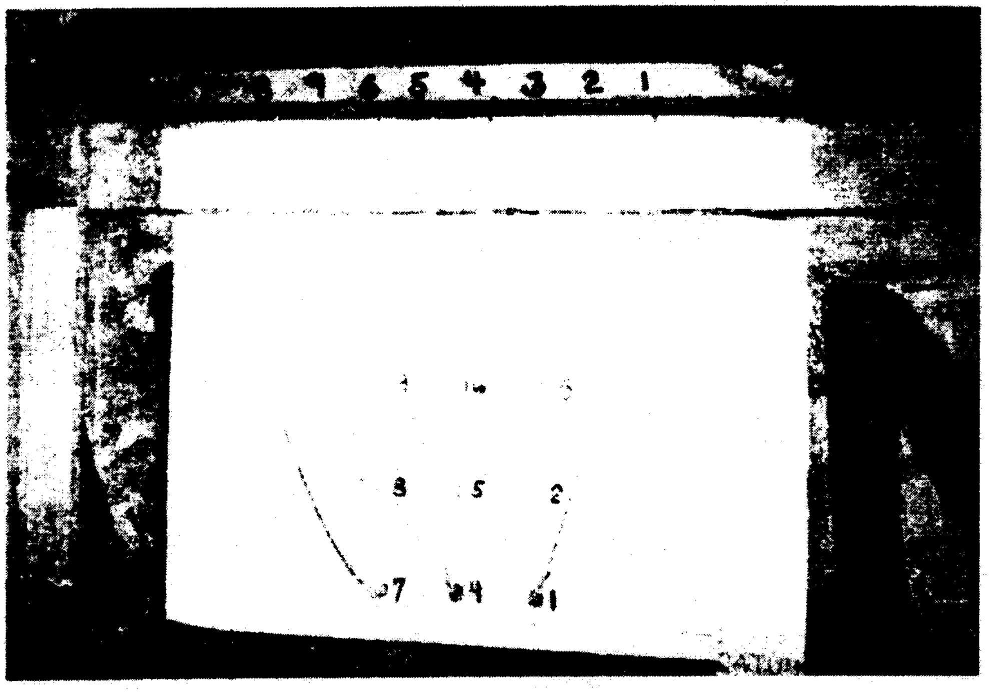

Figure 2.9. Piezometer Nest.

Figure 2.10. Various Rock Sizes Used as Porous Media (from left to right -- large stone, medium stone, small stone).

Chapter 6

SUMMARY AND CONCLUSIONS

6.1. Summary

A series of laboratory flow tests was conducted on angular limestone rock. The purpose of these tests was to determine if a rock-filled gabion dam could be used in storm water management facilities to store and properly release storm water runoff at the predevelopment "target" rates.

The results of the gradation and flow-through tests were applied to the Forchheimer [5,6] relationship for flow through large-size media. The equation was modified to fit the observed data. A single design equation was developed, which is a function of rock diameter, flow path length, ponding depth, and width. The equation is

$$Q = \frac{h^{3/2}W}{\left[\frac{L}{D} + 2.5 + L^2\right]^{1/2}}$$

where

Q = total flow through the gabion dam (cfs)
h = ponding depth in the basin (ft)
W = total length of the gabion dam (ft)
L = horizontal flow path length (or width of the gabion dam) (ft)
D = average rock diameter (ft)

The design equation was checked against the observed values, and then used in a routing sequence in a sample detention basin. The design and routing results yielded reasonable values using a gabion dam to store and release storm water runoff.

6.2 Conclusions

The results of this study indicate that properly sized and configured gabion dams can store significant amounts of storm water runoff and release it at or below the predevelopment "target" discharge rates. However, several key questions remain:

1. How are gabion dams constructed, and is it a very labor-intensive effort?

2. Where are these types of structures applicable, and what advantages do they offer?

3. Do they eventually clog up with leaves, grit, and debris?

4. Will review boards and municipal engineers accept these types of structures as a viable alternative to more traditional methods?

5. How do gabion dams respond in the field to actual storm events?

Question 1:

The construction of a gabion is not a terribly labor-intensive effort; however, a reasonable amount of care should be taken to preserve the integrity of the structure. The rock should be placed in the baskets in layers and then moved (or kicked) into place to minimize void space and to prevent future settlement. Cross-tie wires should be installed to prevent "bulging" of the baskets. Rock may be flat-faced against all sides of the baskets for aesthetic purposes. Adjacent baskets should be wired together to prevent possible future movement. Considering that, on average, relatively few gabion baskets will be required in the construction of the dam, the labor effort is minimal.

Question 2:

A gabion dam can be used almost anywhere; however, they are most applicable on heavily wooded sites, or on sites where excess fill is not available for the construction of traditional dikes. In some instances they may prove to be the most cost-effective means of constructing an outlet structure. They also dissipate the energy of the flow and can discharge the collected runoff as shallow overland flow, as opposed to concentrated swale or pipe flow. A gabion dam inherently constitutes its own spillway. Some may argue that these structures are actually more appealing and tend to blend into a residential setting much better than traditional structures, such as a concrete riser box or a perforated corrugated steel pipe riser in a detention basin.

Question 3:

Some clogging of gabion baskets may occur, especially if using smaller-sized rock media. Leaves and other organic material decompose quickly and are washed through along with fine grit and sand during the next substantial storm. Gabion dams are actually a self-cleansing structure. However, if clogging is of major concern, additional freeboard could be added to the height of the structure. The gabion dams designed by C. Weir (Ambler, PA) have been in operation for over 15 years in a variety of settings and show no apparent clogging of the void spaces. In fact, they seem to be functioning as intended.

Question 4:

Most municipal storm water management ordinances have a section which addresses alternative measures of control and release of runoff. While the term "gabion dam" may not be written out, the phrase " . . . or other alternative designs are permitted as determined by the Municipal Engineer." The Model Storm Water Management Ordinance for Municipalities in the Centre Region of Pennsylvania does have a provision for the use of rock-filled gabions. In other regions, the design engineer and/or project owner may have to "sell" this concept to the review boards and municipal engineers. The findings of this report and any other information the HRC at Penn State can provide may be used as credible evidence during negotiations.

Question 5:

There is no documented research available on the storage and release of storm water runoff from gabion dams in actual field conditions, although existing structures appear to be doing their intended job. A logical extension to this study would involve the design, construction, monitoring, and evaluation of gabion dams in field conditions during actual storm events to determine their effectiveness.